3.5.1 Newton's laws of motion

	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	Newton's three laws of motion	HSW7
(b)	linear momentum; $p = mv$; vector nature of momentum	
(c)	net force = rate of change of momentum; $F = \frac{\Delta p}{\Delta t}$	Learners are expected to know that $F = ma$ is a special case of this equation. HSW9, 10 *M2.1, M3.9*
(d)	impulse of a force; impulse = $F\Delta t$	
(e)	impulse is equal to the area under a force–time graph.	Learners will also be expected to estimate the area under non-linear graphs. HSW3 Using a spreadsheet to determine impulse from F–t graph. *M3.8, M4.3*

3.5.2 Collisions

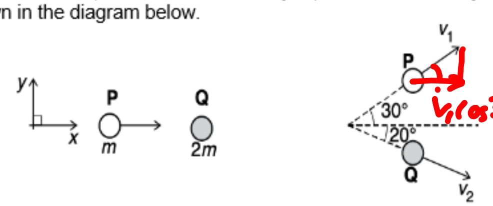
	Learning outcomes	Additional guidance
	Learners should be able to demonstrate and apply their knowledge and understanding of:	
(a)	the principle of conservation of momentum	HSW7
(b)	collisions and interaction of bodies in one dimension and in two dimensions	Two-dimensional problems will only be assessed at A level. HSW11, 12
(c)	perfectly elastic collision and inelastic collision.	HSW1, 2, 6

(6) M - State Newton's 2nd law
(7) S - Explain Newton's second law in terms of equations
(8) C - Select and use equations to problems related to Newton's 2nd law

Newton's 2nd law

STARTER:

A ball **P** of mass m has a velocity in the positive x-direction. It makes a collision with a stationary ball **Q** of mass $2m$. After the collision, the ball **P** has velocity v_1, ball **Q** has velocity v_2 and the balls travel in the directions shown in the diagram below.



before after

$\cos 30 = \frac{V_{1x}}{V_1}$

$V_1 \cos 30 = V_{1x}$

After the collision, the total momentum of the balls in the x-direction is p_x and the total momentum in the y-direction is p_y.

Which row is correct for p_x and p_y?

	p_x	p_y
A	$2mv_2 \cos 20° + mv_1 \cos 30°$	0
B	$2mv_2 \sin 20° + mv_1 \sin 30°$	0
C	$2mv_2 \cos 20° + mv_1 \cos 30°$	$2mv_2 \sin 30° + mv_1 \sin 20°$
D	$2mv_2 \sin 20° + mv_1 \sin 30°$	$2mv_2 \cos 30° + mv_1 \cos 20°$

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Newton's 2nd law $F \propto \frac{\Delta p}{\Delta t}$

The net / resultant force acting on an object is directly proportional to the rate of change of momentum, and is in the same direction.

Underline the 4 key terms / phrases that the examiner would need to see. Explain 2 to your partner.

2nd law

Ex: How could you express this law as a formula?

$$F \alpha \frac{\Delta p}{\Delta t}$$

$$F = \frac{k\Delta p}{\Delta t} \qquad k = 1$$

$$\boxed{F = \frac{\Delta p}{\Delta t}}$$

net force = rate of change of momentum

Ex: Can you manipulate this equation for the special case which occurs when the mass of an object is constant during the acceleration.

E.g to find F = ma

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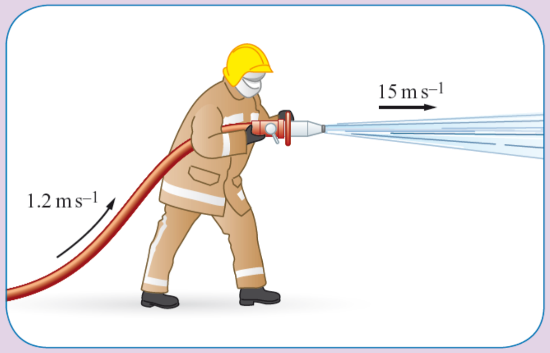
Investigating Newton's 2nd law

Mini plenary Calculate the force needed to push the water forward.

Ex: Why is this information important for the fireman? Use physics principles in your answer.

Figure 2.2 shows a hosepipe squirting water at a rate of 6.0 kg per second. The water moves through the pipe at $1.2\,\mathrm{m\,s^{-1}}$, and leaves the nozzle at



Main: Complete the practical sheet to investigate Newton's 2nd law

Step 1 We will consider a time interval Δt of 1.0 s. In this time, 6.0 kg of water leaves the hosepipe. We have:

$$\Delta t = 1.0\,\mathrm{s} \qquad m = 6.0\,\mathrm{kg}$$
$$u = 1.2\,\mathrm{m\,s^{-1}} \qquad v = 15\,\mathrm{m\,s^{-1}}$$

Step 2 Use Newton's second law to determine the force F.

$$F = \frac{\Delta p}{\Delta t} = m\left(\frac{v-u}{t}\right)$$

$$F = 6.0 \times \left(\frac{15-1.2}{1.0}\right) = 82.8\,\mathrm{kg\,m\,s^{-2}} \approx 83\,\mathrm{N}$$

The force F accelerating the water out from the hosepipe is equal to 83 N and you will also feel a force equal to 83 N pushing back on you. Note that the final units are $\mathrm{kg\,m\,s^{-2}}$, which is the same as N.

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Investigating Newton's 2nd law

Main: Complete the practical sheet to investigate Newton's 2nd law

Questions

1 Consider carefully the total mass that is being accelerated in step **5**. Does this mass remain constant? Give a reason for your answer. (*2 marks*)

2 Suggest how you think increasing the accelerating force will affect the acceleration. (*1 mark*)

3 Suggest how you think increasing the number of masses on the trolley when the accelerating force is constant will affect the acceleration. (*1 mark*)

4 Write an equation in terms of the acceleration, a, the mass of the trolley, M, and the falling mass, m. (*1 mark*)

5 **a** Suggest what graph should be plotted in order to test this equation. (*2 marks*)
b Plot your suggested graph. (*3 marks*)
c What conclusions can you draw from your results and graph? (*2 marks*)

Example data

This is actual experimental data and as such may contain errors.

Trolley mass = 1 kg

Mass on trolley at the start = 500 g

Falling mass / g	Acceleration of trolley / m s^{-2}
100	0.69
200	1.38
300	2.07
400	2.64
500	3.40

Answers for method sheet

1 Total mass remains constant. (*1 mark*)

The total mass being accelerated is $M + m$ (the mass of the trolley **plus** the accelerating mass). (*1 mark*)

2 The acceleration will increase if the falling mass is increased. (*1 mark*)

Allow: A graph of the accelerating force (= $m\,g$) against the acceleration will have a positive gradient. (*1 mark*)

3 The acceleration will decrease if the number of masses on the trolley is increased while the accelerating force is constant. (*1 mark*)

Allow: A graph of m against $\frac{1}{a}$ will have a positive gradient. (*1 mark*)

4 $m\,g = (M + m)\,a$ (*1 mark*)

More able students could be encouraged to include friction in their equation giving $m\,g - F_0 = (M + m)\,a$, where F_0 is friction (which may not be constant).

5 **a** $(M + m)\,a$ on the y- axis (*1 mark*) against m on the x- axis (*1 mark*).

b The graph should be a straight line with a negative intercept. (*1 mark*)

Students should use a suitable scale with the graph taking up most of the graph paper. (*1 mark*)

At least half of the points should be checked for accurate plotting. (*1 mark*)

c Students should conclude:

The graph is a straight line with a gradient that should be equal to g. (*1 mark*).

If the percentage difference between their value and the actual value for g is less than 10% then they should appreciate that this is close to the actual value and variation is probably cause by experimental uncertainty. (*1 mark*)

or

If the percentage difference between their value and the actual value for g is more than 20% then they should appreciate that their result is outside of experimental error. Allow suggestions that they may have made a mistake during their calculations. (*1 mark*)

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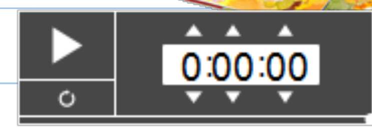
Activity:

Try the summary questions on P106

Self assess and evaluate.

Ex: Derive an equation for when the mass is not constant e.g when a rocket takes off, and uses up fuel at a constant rate.



Plenary

1. Newtons 1st law
2. Newtons 3rd law
3. Newtons 2nd law
4. Write newtons second law as an equation.
5. Show how to derive F=ma from Newton's 2nd law

Mini plenary

23 When a gardener aims water from a hosepipe at the ground, he notices that the water always splashes in many directions. Fig. 22.1 shows the splashes produced by a vertical jet of water hitting the ground.

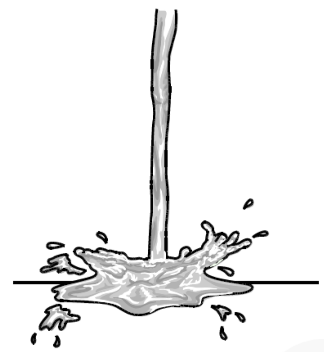


Fig. 22.1

(a) Using ideas about momentum explain why the water splashes in many directions.

✓ Stating law of conservation of momentum.

✓ Total original horizontal moment = zero.

✓ ∴ after = zero (still)

✓ Splashes in all directions means momentum in any horizontal direction is zero due to equal momentum in opposite directions.